Art. VII.—*An Intercomparison of Important Standard Yard Measures.*

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In the year 1843 a committee[1] was appointed to superintend the re-establishment of the standards of length and of weight with a view of replacing the standards destroyed by fire in 1834. Forty similar bronze bars were cast in 1845, each bar 38 inches long, and one inch square in cross section. Near each end a cylindrical hole half an inch in diameter, and half an inch deep was sunk, the distance between the centres being 36 inches. At the bottom of each hole is a gold plug about 0.1 inch in diameter with three fine lines at intervals of about 0.01 inch transverse to the axis, and two lines about 0.03 inch apart parallel to the axis. The distance to be measured is that between the middle transverse lines measured from mid-way between the longitudinal lines.

One of these bars was taken as a reference standard, and each of the others was compared with this. At the close of the comparisons the bars were numbered, and the temperature at which each was standard was engraved on the top surface, which bore the following inscription:—

> "Copper 16 oz. tin 2½ zinc 1 Mr. Baily's Metal No. . . . Standard Yard at .... Fahrenheit. Cast in 1845. Troughtons & Simms, London."

Bar No. 1, Standard Yard at 62.00°F. was chosen as the Imperial Standard for determining the length of the Imperial Standard Yard,[2] and four others as Parliamentary copies. The reference yard was preserved to serve as a standard for reference, while the remaining bars were distributed throughout the world. One bar—No. 40, Standard Yard at 61.99°F.—is in the possession of the Melbourne Observatory. It differs from the others in that on the top surface "Experimental Bar A" is engraved instead of "Cast in 1845." No special reference is

1. G. B. Airy, Account of the Construction of the New National Standard of Length, Phil. Trans., Vol. 147. Part III., 621—702, 1857.
2. Weights and Measures Act, 1878, First Schedule.

made to this in the Committee's report; presumably it was cast shortly before the other bars. This bar is in good preservation and the lines on the plugs are very good.

There is also at the Melbourne Observatory a second standard yard of similar metal and of the same length and cross section. The cylindrical holes are $\frac{1}{4}$-inch in diameter, and only 0.1 inch deep, with gold plugs as before, but the lines parallel to the axis are $\frac{1}{8}$-inch apart. The lines are not good, the central one on one plug being distinctly curved, and on the other not of uniform width. This bar was constructed in 1864, and is marked as standard at 57° Faht. The certificate issued by the Exchequer is dated 4th June, 1866. The bar will be referred to as (1383).

The expansion of 36 inches of the bronze used is given by Airy as 0.000341 ins. per degree Fahr. (l.c., p. 681), so that, assuming the permanence of the bars, the original comparisons would give (40)—(1383)= —.00170 inches when the bars are the same temperature. In August, 1915, these two bars were compared, and preliminary measures showed that (40)—(1383) = +.002 inches. At this time the history of (40) was unknown to me, but the workmanship gave evidence that it had been prepared with much greater care than (1383). The temperature at which the bars were standard was given in the one case as 61.99° F., in the other as 57° F. This pointed to the work of comparison of (40) having been more accurately carried out. The difference between the original and the later comparisons was so marked that it was impossible from the evidence before me to have any certainty of what the standard yard really was, and it was impossible at that time to send one of the bars to England to be re-investigated. In this difficulty, inquiries were made of the Deputy Warden of the Standards as to the history of bar (40), but before the receipt of his reply, it was identified by means of the paper cited above as being one of the original forty standard yard bars, and it was found that similar standards had been sent to Sydney and to Hobart. Further enquiries showed that these standards were still in existence, and thus a way was opened for an accurate determination of the yard by means of an intercomparison of these three original bars, each a replica of the British Imperial Standard Yard bar. After considerable delay, I was authorised by the Victorian Government to arrange for this intercomparison, and through the courtesy of the Minister for Lands of New South Wales, and

the Treasurer of Tasmania, the bars were brought to Melbourne, and the inter-comparison was carried out by me at the Melbourne Observatory during the months, June-November, 1918.

The New South Wales bar, No. 18, Standard at 62.26° F., was found when examined at the Melbourne Observatory to be in good condition, a few spots only appearing on the main portion of the bar, and the lines on the gold pins were very good. The Tasmanian bar, No. 37, Standard at 62.07° F., appeared in good condition as regards the outer surface, but on examining the lines under the microscope, those on the left hand plug were found to be fearfully scraped and utterly ruined; the only part for pointing on is at one end of the terminal line, outside the longitudinal lines. In the comparisons, pointings on the other terminal line were made at about the same distance outside the longitudinal lines, but evidently the original comparison of the bar cannot be used.

In the meantime the comparator to be used had been improved and had been given its final form, the micrometer screws investigated, and revolution values determined. The two microscopes used were supported in heavy cast iron stands which rested on a massive slate slab on stone piers isolated from the floor, the whole forming a most stable system. The microscopes can be raised and lowered, and the optical axis made vertical by three adjusting screws and lock nuts. The illumination is most important. A small electric lamp was fixed to the microscope tube a little above the objective. The light from it passed through a hole in the tube on to a cover glass inclined at 45° to the vertical, and thus the light was thrown vertically through the objective on to the line on the bar. This arrangement gave a good illumination. It could be somewhat improved by interposing a lens between the lamp and the hole in the tube, thus enabling the lamp to be moved further away. The lamp was switched on only while the pointing was being made.

Two girders were bolted across from pier to pier, and on these were supported the rails on which the heavy wooden moving table ran. Cast iron tables, planed on the upper surface, three ins. wide and 48 ins. long, were supported near the ends by strong screws, fixed firmly into iron castings screwed to the moving table. These screws served for raising and lowering the cast iron table through a range of three inches. There were two of these tables side by side separated by a space of one inch.

Each of the two standard yards being compared was supported by a system of eight rollers, connected in groups of four, equispaced as described on p. 629 of the Phil. Trans. Vol. 147, the interval being $38/\sqrt{63}$ inches. The main support of each system of four rollers was a casting resting on three screws, the points of the screws being fixed relative to the tables by a point slot and plane arrangement.

With the limited means at my disposal it was impossible to have a constant temperature bath, but provision against rapid change in temperature was made by enclosing the whole of the supporting tables and the standards in a box, of which the moving table formed the bottom, the sides and top being wooden frames with panels of zinc outwards, and thick strawboard inside. The top was in three sections, to leave space for the microscopes to pass through. Two thermometers were supported horizontally midway between the standard bars. Throughout the whole comparisons the greatest care was exercised to eliminate the effect of any progressive change, and the bars were measured in every arrangement. Thus in comparing two bars, A and B, eight series were made.

North/South: A/B, A/ꝑ, ∀/ꝑ, ∀/B, B/∀, B/A, ꝑ/A, ꝑ/∀,

so that any constant difference in temperature caused by the presence of the observer, who always was to the north, should have no effect on the final result. A series consisted of eight sets, the pointings in a set being in the order a, b, c, d, d, c, b, a where a, b, are the terminal lines on one bar, c, d those on the other bar. In the sets the first pointing was made on each line in turn. A series occupied about half an hour, and during this time the temperature of the thermometers in the box rose about 0.3°C. At the close of a series, the bars were placed in position for the next series, and a minimum time of about two hours elapsed before the next series was started. It is hoped that with the precautions observed any difference in temperature is entirely eliminated from the final mean.

There were thus in all 64 comparisons between any pair of bars, and in each comparison eight pointings were made, arranged symmetrically so as to eliminate any linear progressive change. There is no need to give full details of the readings; it will suffice to state that in no case did the difference between the extreme readings in the 32 comparisons of a group of four series exceed .00020 inch, this including all sources of error

except that arising from a constant difference in temperature between the bars depending on which occupied the North position.

The final mean from the comparisons are expressed by the following equations of condition, the subscript numbers referring to the mean temperature of comparison, and the absolute term being in inches.

			Computed	O−C.
$(37)_{52\cdot4}$	$-(40)_{52\cdot4}$	$=+\cdot00018$	$+\cdot00019$	-1×10^{-5}
$(18)_{49\cdot2}$	$-(37)_{49\cdot2}$	$=-\cdot00034$	$-\cdot00035$	$+1$
$(37)_{48\cdot7}$	$-(1383)_{48\cdot7}$	$=+\cdot00176$	$+\cdot00173$	$+3$
$(18)_{53\cdot3}$	$-(40)_{53\cdot3}$	$=-\cdot00016$	$-\cdot00016$	0
$(1383)_{56\cdot0}$	$-(18)_{56\cdot0}$	$=-\cdot00136$	$-\cdot00137$	$+1$
$(1383)_{61\cdot2}$	$-(40)_{61\cdot2}$	$=-\cdot00152$	-00153	$+1$

The bars are all of the same alloy, and so the coefficients of thermal expansion can be assumed equal, and the equations solved for the three unknowns: (18)—(40), (37)—(40), and (1383)—(40). Giving equal weight to each equation the solution is—

$$(18)=(40)-.00016 \text{ ins.}$$
$$(37)=(40)+.00019 \text{ ins.}$$
$$(1383)=(40)-.00153 \text{ ins.}$$

(37) is so badly injured that the original determination cannot be used for fixing its length, while for (1383) it is almost certain that some error has been made in the reductions of the original comparisons. Hence only (18) and (40) remain for establishing the yard. The original comparisons give the temperatures at which they are standard as 62.26°F. and 61.99°F. respectively, from which it follows—

Original comparison, $(18)-(40)=-.00009$ ins.
Present comparison, $(18)-(40)=-.00016$ ins.

so that a relative change of .00007 inches between the two standards is indicated. This is of the order of changes shown between the similar bars which serve as Parliamentary Copies (see Report by the Board of Trade (Weights and Measures), 1912, p. 11). To distribute this change, assume that (18) has diminished by half the amount, while (40) has increased by half the amount. This change of .000035 inch corresponds to a change in the standard temperature of 0.10°F.

The final results are given in the following table:—

Bar.	Standard at		Length at 62° F.		Difference.
	Original.	Present.	Original	Present.	P–O.
			in.	in.	in.
18	62·26° F.	62·36 F.	1 yd. – ·00009	1 yd. – 00012	– ·00003
40	61·99	61·89	+ 0	+ 4	+ 4
37	62·07	61·32	– 2	+ 23	+ 25
1383	57	66·4	+ 171	– 150	– 321

The changes shown in bars (18) and (40) are quite probable. The change in bar (37) can be explained by the fact that pointings in the present series had to be made on a small part near the end of one of the terminal lines, instead of midway between the two longitudinal lines. The difference in bar (1383) is altogether too large to be explained by a change in the length of the bar. The most probable explanation is that in the original comparison a mistake was made in the sign of the correction—that the bar, instead of being too long, as shown on the certificate, was in reality too short. This would assume that the temperature of comparison was 61.7°F., a quite likely temperature.